PRESENT DAY WATER FILTRATION PRACTICE

By George A. Johnson

It is now eighty-five years since the first municipal water filter was built at London, and this filter was built to perform only the functions of a mechanical strainer for the removal of suspended matter. The two most important water-borne diseases, typhoid fever and cholera, had not then been discovered, nor, indeed, was the germ theory of disease seriously advanced until some twenty years later. Doubtless even the earliest water filters were of considerable sanitary benefit, but the first official recognition of water filtration as a means of reducing the dangers in impure drinking water followed the severe cholera epidemic of 1849. This took the form of an act of Parliament (1852) which made compulsory the filtration of the entire water supply of the Metropolitan District of London.

Typhoid fever as a specific disease was discovered about 1829, and Koch discovered the cholera spirillum in Calcutta water in 1883. In 1889 Brouardel attributed 90 per cent of all cases of typhoid fever to contaminated water, but it was not until 10,000 lives had been sacrificed during the Hamburg cholera epidemic of 1892 that the conviction spread broadcast that impure water was surely responsible for this stupendous epidemic, the happy experience of Altona, the sister city of Hamburg, furnishing unmistakable proof of the efficacy of water filtration.

The first filter at London, as well as all those that followed during the succeeding fifty years, was of the slow sand, or English type. This type of filtration was the subject of much early scientific investigation, particularly in Germany, and was brought to this country in the late sixties by James P. Kirkwood who, in the middle seventies, designed and built at Poughkeepsie, New York, the first municipal water filtration plant in America. Other small plants of the slow sand type were built in this country shortly afterwards, but it is somewhat remarkable that as late as 1880 only 30,000 people in America were being served with water so filtered, and in 1890 but 5000 more.

In 1884 a patent was granted to Isaiah S. Hyatt for a process in which a coagulant was added to the raw water before filtration. This

opened a new era in the art of water purification, although the idea of coagulating water to accelerate clarification was practiced by the Chinese thousands of years ago. Indeed there is a reference in the Holy Writ which seems to refer to this same idea (II KINGS, 2, 19–22).

With the use of coagulating chemicals there developed an entirely new type of water filter, which became known as the American, mechanical, or rapid sand filter, as distinguished from the English, or slow sand filter. Today, although there are variations from the parent types, the two recognized methods of water filtration are slow sand filtration and rapid sand filtration.

It is not necessary to describe these two methods of water filtration. The object of this paper is rather to trace the development of each type; to compare their relative applicability to meet varying sets of conditions; and, since neither can be operated automatically, to discuss certain features of operation upon which the efficiency of both types depend; and, also, to dwell somewhat on questions of the comparative cost of filtered water obtained by the two methods.

GROWTH OF SLOW SAND FILTRATION IN THE UNITED STATES

Between 1875, when the first American slow sand filter was built at Poughkeepsie, New York, and January 1914, some thirty municipal filters of this type were put in operation or are now under construction; and at this date such plants have a daily filtering capacity of about 840,000,000 gallons, and are designed to serve a total population of some 5,500,000. Of this population 721,000, or about 12 per cent of the total is located in New England, where Providence, Rhode Island, New Haven, Connecticut, Lawrence and Springfield, Massachusetts are the largest cities having slow sand filter plants. Of the remaining population in the United States served by slow sand filter plants the bulk is centered in the cities of Albany, New York, Philadelphia, Pittsburgh and Reading, Pennsylvania, Washington, District of Columbia, Wilmington, Delaware, Indianapolis, Indiana, and Denver, Colorado. The present population of these eight last named cities is about 4,000,000, representing about 73 per cent of the total. The remainder of the population served by this type of filters, equivalent to about 15 per cent of the total, is widely scattered through some twenty cities.

Lawrence, Massachusetts. In a relatively large number of instances local preliminary experiments were conducted ahead of the actual

construction of filter plants. Such studies were carried on at Lawrence for some five years prior to the construction of the Lawrence City filter, which was built in 1893 and enlarged in 1907. Slow sand filtration was the only method tested, as rapid sand filtration had but little standing at that time. This plant has done excellent work in the purification of the polluted, but quite clear Merrimack River water, the filters being operated at rates of filtration of about 3,000,000 gallons per acre daily. The old filter is uncovered, and has always given trouble during cold weather on account of the accumulation of ice on the surface, making cleaning operations difficult, and at times impossible. Neither of the filters is equipped with rate controlling apparatus, and it is therefore impossible accurately to tell at a given time at just what rate the filter is actually operating.

The reduction in the typhoid fever death rate in Lawrence, following the installation of the city filter, was very marked. Whereas for the twenty years preceeding 1894 the average annual death rate in Lawrence from this disease was 109 per 100,000 population, the annual average for the last twenty years with filtration was 23 per 100,000, a reduction of 79 per cent.

Albany, New York. This slow sand filter plant, constructed in 1898–99, was, at the time it was built, the largest vaulted masonry filter plant in the United States. It was designed to furnish 15,000,000 gallons of filtered water daily. The water was allowed some two days plain sedimentation before being applied to the filters, but as the Hudson River is a semi-muddy stream, at times becoming very muddy for short periods, such preparatory treatment was found to be inadequate and a battery of roughing filters was installed in order to bring about a more complete removal of suspended matter before the water was applied to the final filters. The necessity for this step is apparent from the following figures which show the average range in turbidity of the raw Hudson River water at Albany. The average annual turbidity is about 40 parts per million.

Range in turbidity of Hudson River water at Albany, New York

RANGE IN TURBIDITY (PARTS PER MILLION)	NUMBER OF DAYS	PER CENT OF ENTIRE YEAR
50	55	15
100	25	7
200	10	3

Formerly, before the preliminary roughing filters were added to the original layout, the filtered water was sometimes noticeably turbid, and the bacterial efficiency, particularly during cold weather, fell off markedly. Of late years the sterilization of the final product with hypochlorites has resulted in a filtered water of first class bacterial quality; but since the river water contains some 30 parts of color on an average, and filters of this type are unable completely to remove such color, the filtered product frequently is more or less unsatisfactory in this respect, and will continue to be so unless coagulating chemicals are used for the removal of such vegetable stains.

The efficiency of the Albany filters in reducing the typhoid fever death rate in that city has been very marked. For the ten years previous to the construction of the filtration plant the average death rate from this disease was 90 per 100,000 population; and for the 13 years ending 1912 the average rate was 21, a reduction of about 77 per cent.

Washington, District of Columbia. This 100,000,000 gallon slow sand filter plant, completed in 1906, is one of the largest of its type in the United States. Before the existing works were placed under construction careful preliminary studies were made to determine the relative applicability of slow sand and rapid sand filters to the purification of the Potomac River water. Lieutenant Colonel A. M. Miller, in reporting the results of these studies to Brigadier General John M. Wilson, Chief of Engineers, U.S.A., recommended that for the filtration of the Washington water supply the rapid sand filtration system should be adopted, for the following reasons:

These investigations have continued during a period of nine months. During this period the Potomac water has passed through extreme stages, from clear to very turbid. With the exception of a few days it has been very turbid from December 28, 1899, to March 13, 1900.

During this period the English (slow sand) filter has not furnished a satisfactory effluent, either as to turbidity or bacterial efficiency.

During the same period the American or mechanical (rapid sand) filter has furnished an effluent which was entirely satisfactory, both as to turbidity and numbers of bacteria present.

At no time has there been any indication of sulphate of alumina present in the effluent of the mechanical (rapid sand) filter.

It is therefore demonstrated that during the period of greatest turbidity and accompanying bacterial danger the English filter will not furnish a satisfactory effluent; while, on the contrary, during this period the mechanical (rapid

sand) filter will, with proper attention, furnish an entirely satisfactory effluent both as to turbidity and sanitary considerations.

Colonel Miller's recommendations were not carried out, one of the reasons being the existence in Washington of a more or less popular prejudice against the use of a coagulating chemical in connection with the purification process. Early in 1901 an expert commission recommended the adoption of the slow sand filter process

. . . . With such auxiliary works as may be necessary for preliminary sedimentation, and the use of a coagulant for a part of the time. There is no reason to believe that the use of this coagulant will in any degree effect the wholesomeness of the water.

When the bill providing for the construction of the filtration plant was finally passed it did not include an appropriation for the coagulant but which in recent years has been used.

The Potomac River is somewhat peculiar, in that the turbidity of its waters ranges from some 3000 to practically nothing; but it is the practice to close the inlet gates on the river at Great Falls when the turbidity of the river water reaches 500 or more. In the year 1912 the gates were closed some 21 per cent of the time, and by this means some 30 per cent of the total suspended matter, that would otherwise have entered the purification system, was excluded.

The reservoir system, through which the water passes on its way to the filters, provides a total period of sedimentation of some six or seven days. Since 1911 sulphate of alumina has been applied to the water in the middle reservoir (Georgetown) on about one-third of the days in the year. On some occasions the filtered water possesses a noticeable turbidity, but on account of the present complete preparatory treatment it is normally free from turbidity and the bacterial efficiency high. The efficiency of the purification plant is well shown by the figures given in the following table:

Efficiency of Washington water purification system

Turbidity

	RESERVOIR OUTLET	1907	1908	1909	1910	1911	1912	AVERAGE FOR SIX YEARS
Maximum	Dalecarlia	250	340	200	200	120	700	300
	Georgetown	150	250	170	215	70	70	155
	McMillan Park	250	160	85	120	40	40	116
	Filtered water	13	20	8	9	1	4	9
Average	Dalecarlia	46	53	50	30	18	59	43
	Georgetown	37	45	32	29	16	23	30
	McMillan Park	29	31	22	18	10	13	22
	Filtered water	2	2	1	1	0	0	1

Bacteria

	RESERVOIR OUTLET	1907	1908	1909	1910	1911	1912	AVERAGE FOR SIX YEARS
Maximum	Dalecarlia	24,000	65,000	12,000	175,000	49,000	119,000	74,000
	Georgetown	23,000	52,000	13,000	180,000	25,000	20,000	52,000
	McMillan Park	15,000	19,000	3,500	180,000	25,000	10,100	44,000
	Filtered water	200	900	160	2,800	300	460	800
Average	Dalecarlia	1,940	2,700	1,950	13,850	3,370	6,000	4,970
	Georgetwon	1,680	2,940	950	10,850	2,080	2,600	3,350
	McMillan Park	635	1,250	390	6,820	1,390	1,100	1,930
	Filtered water	31	55	21	143	38	35	54

The typhoid fever reduction in Washington has not been so marked as that noted in other cities following the filtration of the water supply. For the six years prior to the construction of the filtration plant at Washington the average death rate from this disease was 57 per 100,000 population; and for the following six years ending 1912 it was 31, a reduction of 54 per cent. In view of the good work done by the filter plant it is probable that no inconsiderable part of the typhoid fever in Washington during this latter period came from other sources than impure water. It is a fact that there has been a more or less steady annual decrease in that disease in Washington since the filter plant was put in operation, the death rate by years for the period 1907–12 being 36, 39, 33, 25, 22, 23, respectively, per 100,000 population.

Philadelphia, Pennsylvania.—A long series of preliminary studies were carried on in Philadelphia before and during the early stages of construction of the filtration system of that city. Although the Schuylkill and Delaware Rivers, from which the water supply is taken, are to be classed among the medium muddy waters, the experimental studies were confined to slow sand filtration systems, it being decided well in advance of the commencement of actual design of the works that the rapid sand process should be eliminated from consideration.

About 65 per cent of the present supply is taken from the Delaware River and purified at the Torresdale plant which has a daily capacity of 250,000,000 gallons. The remaining four plants, at Upper Roxborough, Lower Roxborough, Belmont and Queen Lane, respectively, take water from the Schuylkill River, and have a combined daily capacity of 142,000,000 gallons. At the three last named filter plants the water is prepared for slow sand filtration by plain sedimentation and filtration through preliminary filters in order to remove as much as possible of the suspended matter in the raw water. Plain sedimentation only is used at the Upper Roxborough Plant.

That the introduction of filtration plants at Philadelphia has been the direct cause of a marked reduction in typhoid fever in that city there can be no doubt for whereas for the eight years ending 1907 the average typhoid fever death rate was 54 per 100,000 population, for the five years that followed (1909–12) the average was 22, the averages for the individual years being 36, 22, 17, 14 and 12, respectively. The materially lower typhoid fever death rate in recent years may be, and probably is, in some measure due to the use of hypo-

chlorites to sterilize the final filtered product, as is also the practice at the Albany slow sand filter plant. The first filter contract was let in 1901, and the various plants were finished and placed in operation one after another during the ten years that followed, a greater proportion of the population being supplied as each successive plant went into service. This also accounts for the consistently decreasing typhoid fever death rate.

In connection with the applicability of slow sand filters to the treatment of such clay bearing waters as the Delaware River, some very instructive information was furnished in a paper read before the last annual convention of the New England Water Works Association, held in Philadelphia in September, 1913. In this paper, and in an entirely impartial and unusually candid fashion, there were set forth, the actual difficulties under which a slow sand filter is forced to labor when called upon to purify a water the like of which no slow sand filter should, in the light of past experience, be expected continuously to treat in an efficient and economical manner.

The Torresdale filter plant when built was supposed to be the *dernier cri* in slow sand filter design and construction. No preliminary sedimentation basins were provided at this plant, but 120 preliminary filters, in general of the rapid sand filter type of construction, and having a total filtering area of $1\frac{1}{3}$ acre, were expected adequately to prepare the raw Delaware River water for filtration through the final slow sand filters. The filtering material in these preliminary filters consisted of 15, 3 and 8 inches, respectively of graded gravel, the bottom layer varying in size of particles from 2 to 3 inches and the top layer from $1\frac{1}{8}$ to $\frac{1}{4}$-inch; and on top of the gravel layer was placed a 12-inch layer of sand varying in size of particles from 0.8 to 1 mm. In all important respects the Torresdale preliminary filters, in design and construction, are rapid sand filters. And they are operated like rapid sand filters except in the very important respect to coagulation of the water prior to its application to them. It was the original idea that no coagulants were to be used at any of the Philadelphia filter plants, but their use there is now under serious consideration, if, indeed they are not already being used.

Experience has shown that slow sand filters begin to work disadvantageously when the water applied to them contains for several successive days more than 30 to 50 parts of fine turbidity. At such times the effluent often deteriorates markedly in quality, not only from the standpoint of appearance but also bacterially.

In the year 1912 the water delivered by the Torresdale preliminary

filters to the final slow sand filters had a maximum turbidity of 610 parts per million, and on twenty days the turbidity was in excess of 50 parts per million. Incidentally the effluent of the slow sand filters possessed a turbidity of over 10 parts on nine days, and a turbidity of this intensity is clearly unsatisfactory.

Plain sedimentation and roughing filters will remove much of the turbidity from a muddy water, but, unhappily for those who do not favor the use of a coagulant, the residual turbidity in the effluent of these preparatory processes is caused by suspended matter in a state of fine subdivision. This matter, when applied to slow sand filters, penetrates deeply, indeed in some cases passing completely through the filter and out in the filtered water, to the detriment of the appearance and bacterial quality thereof.

In the paper above referred to the authors state that the Torresdale plant as it exists today, although, by virtue of the use of hypochlorites producing a water of relatively high bacterial purity, can be depended upon to yield a clear effluent but 48 weeks in the year. When the turbidity of the Delaware River water for prolonged periods is in excess of 100 parts per million the existing plant is "utterly unable to cope" with the problem of yielding a satisfactory effluent. At such times the prefilters fail to do their proportion of the work, and the final slow sand filters choke badly and allow fine silt to pass through them. The penetration of suspended matter into the beds is sometimes as great as 10 inches. Under the most unfavorable conditions, in order to maintain the required yield from the plant, it is necessary to continue cleaning operations for 24 hours in the day, under which circumstances about 85 per cent of the filters are doing 100 per cent of the work. High bacterial removal at such times is due solely to the use of hypochlorite, as before stated.

Pittsburgh, Pennsylvania.—Before a decision was reached as to whether slow sand or rapid sand filters should be adopted at Pittsburgh, comparative studies on an experimental scale were made of both systems. The final conclusion was in favor of the adoption of slow sand filtration, and a plant of this type was placed under construction and completed in 1908.

In the light of events which followed the placing in operation of the filtration plant, and which are dwelt upon at some length beyond, some of the conclusions of the Filtration Commission, in recommending slow sand filtration for Pittsburgh are interesting on account of their failure to be confirmed later by actual practice:

Comparative cost

If a conclusion were to be arrived at upon a consideration of initial cost, alone, the decision would doubtless be prompt. While the cost of bare construction differs but slightly as between the two plans, the cost of the larger body of land, required for the sand filtration plant, would be determinative, in favor of mechanical (rapid sand) filtration, were other things equal.

Efficiency

An examination of the relative efficiency of the two methods, in the light of actual experiment, shows that so far as the removal of bacteria from the water is concerned the (slow) sand filter leaves but little to be desired. In addition to bacterial efficiency and somewhat important, is the question of the adaptability of the effluent for steaming purposes. The effluent which yields a minimum scale formation, and shows no corrosive action upon the points in a boiler generally first exposed to attack, is, all other things being equal, to be preferred. We find that the weight of evidence, obtained by experiment is in favor of (slow) sand filtration; so far as efficiency in this respect is concerned.

Simplicity of operation

In operating a plant of such magnitude as will be required to provide a full supply of pure water to this large and growing city it is of the first importance to do it on such lines as not to require, necessarily, the higher grades of technical skill on the part of a large proportion of the operatives. The (slow) sand filter meets this requirement to such an extent as to be fairly considered ideal. When properly constructed, slight neglects and errors of judgment on the part of workmen cannot damage the water. With any filter using coagulant the conditions are different; nice judgment is required to determine from day to day, and at times from hour to hour, the required quantity of that coagulant, and if there be not the proper quantity of lime in the water, initially, that must also be provided. The choice lies between a system, which, when properly constructed, *cannot* furnish impure water, except as the result of wilful neglect, and one which *can* furnish pure water, but which can also, when carelessly or ignorantly handled, easily produce water unfit for domestic or mechanical use. The weight of evidence is found by the Commission to be decidedly in favor of sand filtration, so far as simplicity of operation is concerned.

As an example of the early efficiency of the Pittsburgh filters which were subsequently built in accordance with the recommendations of the Filtration Commission, let it be stated that in 1909 the records show that the filtered water was ordinarily, but not uniformly, satisfactory in appearance. The average number of bacteria in the filtered water for the eleven months ending December 31, 1909 was 3,900 per cubic centimeter. The highest average number for a single month was 34,300 per cubic centimeter in December, 1909. The

highest number of bacteria in the filtered water for any one day was 120,000 per cubic centimeter, recorded on December 15, 1909. In the face of the above results is it any wonder that the use of hypochlorite was inaugurated on January 3, 1910, for the sterilization of the filtered water?

There are very few filter plants where the details of operation are so carefully watched, or where the varying character of the raw water is so well anticipated and adjusted to, as at the Pittsburgh plant. More to this fact than anything else is due the absence of signal failure of slow sand filtration at Pittsburgh; but it has required the "higher grades of technical skill" to enable the filtration works to handle the most difficult water a slow sand filter plant is called upon to purify in this country.

Next to Philadelphia the Pittsburgh slow sand filter plant is the largest of its type in the United States. As designed the 56 acres of filters were to have a daily filtering capacity of about 140,000,000 gallons as a minimum. By virtue of the highest degree of skilled supervision this expectation was realized, but owing to the fact that the pollution of the Allegheny River with trade wastes is rapidly increasing year by year this would not have held true for very many years without the aid of the preliminary filters and improved sedimentation facilities, such as have been installed during the past two years in anticipation of what is to come. At times the capacity of the filters was severely taxed, and to quote from the report of the Pittsburgh Bureau of Water for 1911: "Without some sort of change in the present system it is certainly true that the economical capacity has already been closely approached on several occasions."

The turbidity of the Allegheny River at Pittsburgh fluctuates from almost nothing to very muddy. The main facts surrounding this point are contained in the following table:

Turbidity of the Allegheny River water at Pittsburgh

1911-12 MONTH	TURBIDITY—PARTS PER MILLION				
	Average	Highest day	Days when turbidity was over		
			50	100	200
February	43	134	10	1	0
March	36	61	7	0	0
April	52	175	13	2	0
May	23	62	2	0	0
June	21	69	2	0	0
July	17	70	1	0	0
August	71	758	7	2	2
September	173	1,469	17	12	5
October	129	1,146	15	9	5
November	49	159	9	2	0
December	53	116	11	2	0
January	24	71	1	0	0
Total and Averages	58	....	95	30	12
Per cent of entire year	...	....	26	8	3

The plain sedimentation reservoirs, having an average period of storage of about thirty-six hours, were the only provision for preparatory treatment in the original design. They were never very efficient in removing suspended matter from the raw water, such removal averaging about 25 per cent through a representative year. Taking the figures in the last table as an example, it is seen that with 25 per cent of the suspended matter removed in these reservoirs the water as applied to the filters during the months of August, September and October would have contained 53, 130, 87 parts per million of suspended matter during these three successive months. On quite a number of occasions the water applied to the filters contained for several successive days at a time from 150 to 250 parts per million of suspended matter. During 1909 the effluent of the sedimentation reservoirs had a turbidity in excess of 25 parts per million for more than half the time, and in excess of 50 parts for some 15 or 20 per cent of the time. Such conditions as these in general could only mean that the final filters would frequently be overloaded and inefficient.

In July 1910, about a year and a half after the works were put into operation, the whole filtration problem at Pittsburgh was placed under

investigation. It was recognized in the beginning that the filters would soon be unable to supply the demand for water, and the studies which followed, besides covering improved methods of operation in interests of economy, were also particularly directed toward a solution of how best to prepare the Allegheny River water for final filtration through the slow sand filters in order to obtain from them a greater net yield of filtered water, and higher bacterial and physical efficiency.

One object of these investigations was to develop methods whereby the acid conditions existing in the Allegheny River water for much of the time could be so modified as to allow of the adequate preparation of the water for slow sand filtration, so that, with improved methods of operation, it would be possible materially to increase the minimum daily yield of the plant, and at the same time obtain a filtered water satisfactory from the standpoints of appearance and bacterial content.

It was learned during the investigations of 1910–11 that speedy clogging of the filters was due primarily to acid conditions in the Allegheny, coming from mine wastes discharged into the river above the intake of the filtration works. The presence in the river water of unprecipitated colloidal hydrates and silicates of iron, aluminum and manganese, complicated at times by the presence of organic coloring matter, parafine like bodies, sudden changes in mineral constitutents and the temperature, were the controlling factors.

These studies also showed that in order to prepare the water for efficient treatment on the slow sand filters it was necessary to add certain chemicals to the river water for about one-half of the average year, these chemicals being sulphate of alumina, lime, clay, and bleaching powder, either added singly or in combination, according to the character of the river water. It was also considered advisable that all of the river water, whether chemically treated or not, should be passed through contact baffles, the same being built of concrete in tank form and divided into units of about 0.11 acre each, or $2\frac{2}{3}$ acre for a minimum capacity of 200,000,000 gallons daily, the tanks being filled with gravel ranging in size from $\frac{1}{2}$ to 1-inch, the depth of the filtering layer being about 8 feet.

It was also deemed advisable to install latitudinal bafflles in the large sedimentation reservoirs in order to obtain more complete water displacement and thus increase their efficiency.

It was learned in the course of the experimental studies that prolonged plain sedimentation did not eliminate the necessity for using chemicals in the preparatory treatment for probably half the aver-

age year. Without chemical treatment even as long a period as ten days storage would not at all times suitably prepare the water for slow sand filtration.

The results of the studies of 1910–11 were put into effect, and the preliminary filters and latitudinal baffles built, the bulk of the improvements being completed in December, 1913. There now remain to be installed appliances for the introduction of the coagulating and correcting chemicals to the water. When these have been made the slow sand filters will be able to furnish a filtered water at all times satisfactory in appearance and from a hygienic standpoint.

The work of the Pittsburgh filtration plant in reducing the death rate from typhoid fever in that city has been remarkable. Whereas for the 9 years prior to 1909, without filtration, the annual typhoid fever death rate in Pittsburgh averaged 125 per 100,000, for the four years ending 1913, with filtration, the annual average was 10, a reduction of 92 per cent; a result which has never been equalled in the history of water purification.

GENERAL

The foregoing specific comments, referring to the slow sand filter plants at Lawrence, Albany, Philadelphia, Washington and Pittsburgh have been set down to show the difficulties under which filters of this type are obliged to work when called upon to treat muddy waters. It is noted that in every instance, with the sole exception of Lawrence, the original design has been improved upon, and the preparatory treatment of the water made more complete. This was found imperative very shortly after the various plants went into service. Albany has added preliminary roughing filters; Philadelphia already had roughing filters which have proved but a limited success, and the use of coagulants is being considered in connection with preparatory treatment; Washington has added the coagulation process; and Pittsburgh has built roughing filters and is preparing to use coagulants and certain other chemicals.

Of other slow sand filter plants in the United States the Wilmington, Deleware plant includes preliminary roughing filters, as does the plant at Steelton, Pennsylvania; and Springfield, Massachusetts and Indianapolis, Indiana use coagulants. At practically all slow sand filter plants the final filtered product is sterilized with hypochlorites. At Lawrence the clarity of the Merrimack River water makes un-

necessary the use of roughing filters, nor are coagulants used. The same is true at Providence, Rhode Island and New Haven, Connecticut but with these exceptions it is becoming difficult to locate a slow sand filter plant which does not in some important respect depart from the original ideas of what constituted that system of water purification, or which does not in some way make use of certain inherent ideas upon which are based the rapid sand system of water filtration.

GROWTH OF RAPID SAND FILTRATION IN THE UNITED STATES

The first municipal rapid sand filtration plant was built at Somerville, New Jersey in 1885, and between that date and January, 1914, upwards of 450 municipal filter plants of this type have been built or are now under construction in the United States. At this date the total daily capacity of filtration plants of the rapid sand type is 1,745,000,000 gallons, and a total of nearly 12,000,000 people are being supplied with water so filtered. This population is distributed as follows:

Geographic distribution of population served by rapid sand filter plants

District	*Per cent*
New England States	2.0
Middle Atlantic States	22.0
South Atlantic States	10.0
Ohio Valley	26.0
Upper Mississippi Valley	13.0
Lower Mississippi Valley and Gulf	24.0
Rocky Mountain Region	0.2
Pacific Coast	3.2

In 1890 there were very few rapid sand filtration plants in operation in this country, and the decade which followed was fruitful with results of scientific investigation into the merits of the new process. The first series of public investigations were conducted at Providence in 1893, to be followed by even more elaborate studies at Louisville, Kentucky, Pittsburgh, Pennsylvania, Cincinnati, Ohio, and Washington, District of Columbia. These investigations were in no small measure responsible for the wonderful growth of rapid sand filtration during the past 15 years, for the theory of the process was thoroughly worked out, and the whole idea becoming well understood was placed on a solid footing.

The type of construction changed abruptly about 1900, rectangular concrete tanks frequently replacing the circular wooden or steel tanks formerly used. The rectangular shape of the tanks made necessary the use of compressed air to agitate the sand layer while washing the filter, and later the application of wash water at high velocities. Both of these methods of filter cleaning had been used before, and therefore were not new in principle, but their use with rectangular shape filter tanks became more general, and supplanted the mechanical stirrers and wash water applied at low rate used in the older type of rapid sand filters, and from which they derived their original name, "Mechanical" filters.

In the following tables there is given a fairly complete list of the rapid sand filter plants built in the United States since the first one was constructed at Somerville in 1885. In the second of the two tables are listed the new plants built where no rapid filter plant existed before, and also those additions to existing plants made between 1910–1913. All plants under construction on January 1, 1914, are also included in this table.

As will be seen from the following table, in the decade 1900–10 many important rapid filter plants were built in this country, among the largest being Little Falls, New Jersey; New Orleans, Louisiana; Cincinnati, Ohio; Louisville, Kentucky and Columbus, Ohio; the respective daily capacities of these plants being 32, 44, 112, 36 and 30 million gallons. As it is beyond the scope of this paper to describe the experiences at all of the plants listed in the accompanying tables, it will be sufficient to refer in detail only to the five large plants just mentioned, which will be taken up in the order named.

Little Falls, New Jersey. This plant was completed in 1902, and was built for the East Jersey Water Company which supplies with water the cities of Paterson, Passaic, Montclair and several other communities in northeastern New Jersey. The total population supplied from the Little Falls plant is in round numbers 250,000, and the capacity of the filtration plant is 32,000,000 gallons daily.

This was the first plant built wherein the filter tanks were of rectangular concrete construction, and in numerous respects all of the rapid sand filter plants built in the past dozen years are patterned after it with respect to the scheme of layout, and automatic or easily manipulated hydraulic and electrical contrivances.

The waters of the Passaic River, which this rapid sand filter plant

Rapid sand filter plants built in the United States between 1885 and 1910

STATE	NUMBER OF PLACES	TOTAL POPULATION (1910)	TOTAL DAILY FILTERING CAPACITY
			gallons
Alabama	5	172,000	23,325,000
Arkansas	1	46,000	5,500,000
California	6	220,000	14,567,000
Colorado	2	5,000	975,000
Connecticut	2	26,000	3,500,000
Georgia	15	337,000	34,350,000
Illinois	16	321,000	44,650,000
Indiana	12	250,000	42,500,000
Iowa	12	238,000	30,750,000
Kansas	9	115,000	11,850,000
Kentucky	7	330,000	50,250,000
Louisiana	2	367,000	45,000,000
Maine	8	83,000	18,800,000
Maryland	4	15,000	2,550,000
Massachusetts	2	11,000	2,500,000
Michigan	5	45,000	8,910,000
Minnesota	6	37,000	4,528,000
Mississippi	4	55,000	7,300,000
Missouri	13	180,000	24,350,000
Nebraska	1	5,500	400,000
New Hampshire	2	6,500	1,114,000
New Jersey	19	709,000	86,600,000
New York	22	321,000	57,900,000
North Carolina	18	222,000	22,525,000
Ohio	24	1,083,000	216,420,000
Oklahoma	6	112,000	13,500,000
Oregon	3	23,000	3,500,000
Pennsylvania	45	892,000	123,725,000
Rhode Island	7	74,000	13,000,000
South Carolina	6	101,000	16,500,000
Tennessee	5	101,000	17,500,000
Texas	4	38,000	3,950,000
Vermont	1	20,000	2,000,000
Virginia	9	198,000	23,350,000
Washington	2	15,000	1,000,000
West Virginia	5	83,000	13,500,000
Wisconsin	4	65,000	7,360,000
Totals	314	6,922,000	999,999,000

Rapid sand filter plants built and building in the United States during period 1910-1913. (Date of compilation, January, 1914)

STATE	ESTIMATED POPULATION SERVED IN 1914 BY PLANTS BUILT 1910–1914	NUMBER OF PLACES			TOTAL DAILY FILTERING CAPACITY		
		Entirely new plants	Additions to old plants	Total	Entirely new plants	Additions to old plants	Total
					gallons	*gallons*	*gallons*
Alabama	5,700	0	2	2	0	4,000,000	4,000,000
California	25,000	6	1	7	2,140,000	1,000,000	3,140,000
Colorado	11,000	1	0	1	4,000,000	0	4,000,000
Connecticut	29,000	2	0	2	2,000,000	0	2,000,000
Georgia	80,000	4	3	7	3,000,000	14,000,000	17,000,000
Illinois	170,000	11	6	17	21,950,000	18,825,000	40,775,000
Indiana	43,000	2	1	3	12,000,000	1,000,000	13,000,000
Iowa	26,000	2	2	4	1,500,000	8,000,000	9,500,000
Kansas	62,000	9	2	11	9,040,000	5,775,000	14,815,000
Kentucky	22,000	2	2	4	7,000,000	2,000,000	9,000,000
Louisiana	7,100	1	0	1	500,000	0	500,000
Maine	19,000	1	2	3	1,135,000	9,500,000	10,635,000
Maryland	754,000	3	0	3	133,000,000	0	133,000,000
Massachusetts	5,000	1	0	1	500,000	0	500,000
Michigan	200,000	2	1	3	30,000,000	750,000	30,750,000
Minnesota	404,000	3	0	3	41,500,000	0	41,500,000
Missouri	947,000	6	0	6	168,300,000	0	168,300,000
Montana	4,500	2	0	2	2,325,000	0	2,325,000
New Jersey	149,000	2	2	4	30,300,000	3,000,000	33,300,000
New York	114,000	4	3	7	25,750,000	20,000,000	45,750,000
North Carolina	55,000	9	6	15	4,350,000	5,100,000	9,450,000
North Dakota	43,000	3	0	3	7,000,000	0	7,000,000
Ohio	248,000	8	4	12	31,820,000	27,500,000	59,320,000
Oklahoma	37,000	5	1	6	5,750,000	1,000,000	6,750,000
Oregon	24,000	6	0	6	3,967,000	0	3,967,000
Pennsylvania	223,000	16	6	22	44,500,000	9,825,000	54,325,000
Rhode Island	4,500	0	1	1	0	1,000,000	1,000,000
South Carolina	39,000	5	1	6	3,500,000	800,000	4,300,000
Tennessee	13,000	0	2	2	0	5,000,000	5,000,000
Texas	277,000	5	0	5	28,000,000	0	28,000,000
Virginia	1,00	1	1	2	1,000,000	250,000	1,250,000
West Virginia	17,000	3	1	4	3,000,000	500,000	3,500,000
Wisconsin	30,000	2	0	2	5,500,000	0	5,500,000
Wyoming	8,000	3	0	3	1,500,000	0	1,500,000
Totals	4,096,800	130	50	180	635,827,000	138,825,000	774,652,000

was called upon to purify are not muddy, although, as will be shown in the next table, following heavy rains the turbidity will sometimes rise to over 100 parts per million for a day or so. The river above Little Falls is not badly polluted, and the chief objection to it in its raw state is a noticeable color, due to dissolved vegetable matter coming from several large swamps situated on the drainage area. It was to remove the bulk of this color, and to guard against the effects of possible contamination, that the Water Company decided to build the filter plant, a full description of which is given in the *Transactions of the American Society of Civil Engineers*, Vol. 50, p. 394 (1903).

Records of operation of Little Falls, New Jersey, rapid filter plant

MONTH (1912)	SULPHATE OF ALUM, GRAINS PER GALLON	PER CENT WASH WATER USED	PARTS PER MILLION								BACTERIA PER CUBIC CENTIMETERS		
			Turbidity				Color				Average		Highest day in filtered water
			Average		Highest Day		Average		Highest Day				
			River	Filtered	River	Filtered	River	Filtered	River	Filtered	River water	Filtered water	
January	0.74	1.7	7	0	9	0	32	5	38	8	2,100	2	17
February	0.65	1.8	13	0	30	0	35	6	53	11	9,700	6	43
March	0.98	2.7	26	0	118	0	52	6	92	15	10,000	5	60
April	1.07	2.8	8	0	13	0	41	6	46	9	1,600	3	20
May	1.46	3.3	8	0	13	0	55	7	66	11	1,300	2	10
June	1.60	3.3	10	0	12	0	56	8	65	11	1,100	1	3
July	1.65	3.4	9	0	11	0	46	9	55	11	600	4	13
August	1.62	3.4	8	0	17	0	43	9	52	10	700	2	5
September	1.47	3.1	7	0	10	0	41	8	64	10	750	2	4
October	1.93	3.1	10	0	23	0	56	7	78	10	1,100	4	21
November	3.16	3.0	10	0	22	0	61	14	71	22	2,000	4	11
December	1.86	2.3	8	0	12	0	40	11	53	19	1,800	3	10
Annual average	1.51	2.8	10	0	...	...	46	8	...	...	2,730	3	......

The records given in the last table show that while on one day in 1912 the turbidity of the water rose to 118 parts per million the yearly average turbidity of the raw water was only 10 parts. The filtered water was free of turbidity at all times. The color of the unfiltered water reached a maximum of 92 parts per million in March, while the average for the year was 46 parts. The filtered water color averaged 8 parts for the entire year, and here it should be noted that the aim at this plant is to reduce the color so that the filtered water

shall not contain more than 10 or 15 parts. In November and December the color of the filtered water was slightly in excess of this upper limit for short periods. The bacteria in the filtered water averaged 3 per cubic centimeter, and the highest number recorded on any one day during the year was 60 per cubic centimeter.

The average amount of sulphate of alumina used for coagulation during the year was 1.51 grains per gallon, equivalent to 216 pounds per million gallons of water treated. The amount of filtered water used for cleaning the filters averaged 2.8 per cent of all the water filtered during the year. The filters are washed by means of compressed air and wash water applied at the rate of about 8 gallons per square foot per minute.

As to the reduction of typhoid fever, in the largest city supplied by this plant, Paterson, the average death rate from typhoid fever for the 5 years prior to the filtration of the water supply was 32 per 100,000 population, and for the 10 years following, with filtration, the average death rate from this disease was 9, a reduction of 72 per cent.

New Orleans, Louisiana. Before this rapid sand filter plant was built careful investigations were conducted at this city into the relative applicability under the local conditions of the slow sand and rapid sand systems of water purification. These investigations were terminated in August 1901, and in the report prepared from the results obtained the following conclusions were drawn.

Conclusions as to the relative applicability of the slow sand and rapid sand filtration systems in the purification of the water supply of New Orleans.

Three general steps in the systems for clarification and purification have been considered in various combinations, as follows:

1. Plain subsidence in basins for several days.
2. Supplementary subsidence in basins, with the aid of coagulant.
3. Filtration, either at a slow rate through sand beds, or at a rapid rate through filters provided with mechanical devices for cleaning the sand.

On account of the large amount of fine clay particles, the suspended matter is held in suspension indefinitely, and cannot be removed on the average by any practical periods of plain subsidence, even by periods of a week or more. When this subsided water is filtered at slow rates through thick layers of fine sand, a satisfactory clarification and purification results for a portion of the time. However, this system would produce muddy effluents for months at a time, and what is more of a factor, the cost of cleaning and removing the clogged sand layers would be prohibitively excessive.

Since the fine particles of suspended matter cannot be removed by plain subsidence, it is necessary to add something to the water to bring them to-

gether in aggregates or groups which of themselves would have a subsiding value great enough to cause them to settle within a reasonable period. Sulphate of alumina can be used for this purpose, and when added to the water forms a perfectly insoluble gelatinous precipitate, which, uniting with the clay, causes it to gather into flocks or aggregates which settle much more rapidly than the diffused clay particles themselves. This precipitate also has the power of attracting, enveloping, or absorbing stray particles of suspended matter, including bacteria, so that the water by this method of coagulation and supplementary subsidence can be made fairly clear. In practice, water which has been purified by plain subsidence followed by supplementary subsidence with a coagulant is, strictly speaking, never perfectly clear. This is because it is difficult to remove the last traces of turbidity by this process alone. Indeed, it is much more satisfactory to make the final step in the clarification and purification process by the use of a suitable filter.

Two kinds of filters can be used for this final clarification and purification of the effluent of the coagulating basins, namely, the English (slow sand) and American (rapid sand) filters. These filters need but little explanation in this chapter. The English (slow sand) filter, as is well known, consists of a bed of sand through which the water, without coagulation, but after being subjected to plain subsidence, filters at a slow rate; while the American (rapid sand) system treats the water after both plain subsidence and supplementary subsidence with the aid of a coagulant, and filters it at a rapid rate through a bed of sand which is intermittently freed from matter which obstructs the passage of water, by reversed currents of water, and by agitation. In the English (slow sand) filter the accumulated matter which clogs the filter is removed by draining and scraping.

Either filter would be adapted to the purification of the Mississippi River water, and the decision as to which would best suit local conditions should be dependent upon the cost per million gallons of filtered water, taking into consideration the difference in first cost. In the total first cost the American (rapid sand) system is fully 25 per cent cheaper than the modified English (slow sand) system when estimates are made on the same basis.

Taking into consideration all the available evidence, it is concluded that the American (rapid sand) system is best adapted to the purification of the Mississippi River water at New Orleans.

A rapid sand filter plant was built in accordance with the recommendations above cited, and is doing excellent work in the purification of the muddy Mississippi River water. The system consists of preliminary sedimentation basins, chemical mixing and coagulating basins, and rapid sand filters capable of filtering 40,000,000 gallons of water daily. Lime and sulphate of iron are used as coagulants, and the filters are cleaned by the application of filtered water under high velocities, no other means being provided for agitating the sand layer during washing. Summarized results from this plant for the year 1912 are contained in the following table:

Results of operation of New Orleans rapid sand filtration plant

MONTH (1912)	GRAINS PER GALLON COAGULANT		PER CENT WASH-WATER USED	TURBIDITY (PARTS PER MILLION)				BACTERIA PER CUBIC CENTIMETER			
				Maximum day		Average		Maximum day		Average	
	Lime	Iron		River	Settled	River	Settled	River	Filtered	River	Filtered
Jan.....	3.68	0.32	0.6	1,250	60	900	32	3,100	65	2,000	17
Feb.....	3.68	0.59	0.7	675	110	475	40	15,000	65	6,000	27
Mch....	3.51	0.73	0.5	1,600	75	900	35	16,000	3,200*	7,000	500*
Apr.....	3.21	0.98	0.3	1,350	150	950	26	11,000	2,300*	3,000	750*
May....	3.73	1.03	0.3	1,100	100	700	35	8,000	650	2,100	95
June....	4.60	0.25	0.3	1,400	525	625	34	9,500	190	2,800	65
July....	4.46	0.06	0.3	2,200	100	1,350	40	8,500	300	3,300	70
Aug.....	4.51	0.13	0.3	1,850	400	1,100	75	13,000	120	3,400	36
Sept....	4.65	0.11	0.3	1,000	1700	750	65	10,000	85	3,700	34
Oct.....	4.87	0.09	0.3	725	110	550	55	9,500	180	2,000	23
Nov.....	5.78	0.04	0.4	550	190	400	35	32,000	150	1,900	15
Dec.....	5.71	0.05	0.4	675	150	425	35	6,000	55	1,800	10
Annual average	4.41	0.33	0.4	......	......	750	40	....	....	3,300	40

*Abnormal, due to algae growths.

The above results show that with relatively small amounts of coagulating chemicals, and with the very thorough pretreatment of the raw Mississippi River water, the filters delivered throughout the year a water free from noticeable turbidity and containing on an average but 40 bacteria per cubic centimeter. In computing this average the results for the months of March and April are excluded for the reason that the high numbers recorded in those months were caused by algae growths, and after growths of harmless bacteria in the filtered water following the use of hypochlorite. The amount of wash water used in cleaning the filters is also worthy of note, averaging the very low figure of 0.4 per cent of the total amount of water filtered. This was due, of course, to the very complete preparatory treatment given the water prior to its application to the filters.

Before the introduction, in 1909, of the new water works system, including the filtration works, in New Orleans, the city depended for its supply almost exclusively upon cistern water caught from roofs and stored in cypress tanks above the ground. Less than 7,000 premises had connections with the public supply furnished direct

from the Mississippi River. The typhoid and malarial fevers existing in New Orleans prior to 1910 were not largely water borne, but due in the main to the spread of local foci through the agencies of flies, impure milk and other food supplies, and greatly augmented by the general lack of sewerage facilities. Since 1908 the rate at which connections have been made to the new sewer and water systems has been slow, as shown by the following statistics:

Data relative to connections made to sewer and water systems of New Orelans since 1907

BY DECEMBER 31 OF	ESTIMATED POPULATION	APPROXIMATE NUMBER OF PREMISES CONNECTED TO		APPROXIMATE PER CENT OF POPULATION CONNECTED TO	
		Sewers	New Water Works	Sewers	New Water Works
1907	318,000	925	0	1	0
1908	325,000	3,400	2,000	4	3
1909	331,000	9,000	15,800	11	16
1910	339,000	13,800	26,000	16	31
1911	347,000	20,200	38,000	22	41
1912	355,000	28,500	46,000	32	52

The above data indicate pretty conclusively why the typhoid fever death rate has not decreased as sharply as in some other cities, following the installation of water filtration works. But that there has been a sharp diminution in typhoid and malarial fever in New Orleans since the municipal sanitary improvements made, is shown by the statistics given in the following table, compiled from U. S. Census reports. That the reductions noted should have been so great is remarkable in view of the fact that in 1912 but one-third of the population had connected to the sewerage system, and but one-half the population were being supplied with pure filtered water.

Death rates in New Orleans from typhoid and malarial fever per 100,000 population

DATE INCLUSIVE	MALARIAL FEVER	TYPHOID FEVER	PER CENT REDUCTION COMPARED WITH PERIOD 1881-1910	
			Malarial Fever	Typhoid Fever
1881–1910	93	33	..	..
1911	9	31	90	9
1912	8	14	91	58

Cincinnati, Ohio. This rapid sand filter plant is the largest of its type in operation in this country, although larger rapid sand filters are now under construction at St. Louis, Missouri (160,000,000 gallons) and Baltimore, Maryland (128,000,000 gallons). It has a daily filtering capacity of 112,000,000 gallons and was completed in 1907.

In 1896 a special Engineer Commission, investigating conditions for the extension and betterment of the water supply system of Cincinnati, recommended that the Ohio River water be clarified by several days' subsidence and afterwards filtered through slow sand filters. The Commission of Engineers of 1897, however, decided that before proceeding with the filtration project reliable data should be obtained with reference to exact local conditions. Accordingly, an experimental plant was built, consisting of several sedimentation tanks and some fifteen slow sand filters, and the performances of these devices were carefully noted during the year 1898. In the autumn of that year it became apparent that the plan proposed by the Commission of 1896 was of very doubtful expediency, and a series of comparative tests was then begun to show the relative efficiency under the local conditions of the modified slow sand, and rapid sand filtration systems, the former system differing from the usual slow sand process only in that the water was clarified by coagulation and sedimentation before filtration. In January 1899 the following conclusions were reached:

With respect to the slow sand filtration system

In the absence of heavy and long continued freshets in the river, three days' subsidence would be adequate to allow the local water to be satisfactorily clarified and purified by this type of filter (slow sand) and at a reasonable cost. When heavy and long continued rises in the river do occur, the method under consideration would not be a success, with filters constructed within conventional limits as to thickness of sand layer and operated within conventional limits as to rate of filtration. Their failure under such conditions would be due to the excessive turbidity of the effluent; the diminution in bacterial efficiency toward the end of long rises; and to the abnormal expense of cleaning the sand layers.

It would be possible by increasing sufficiently the thickness of the sand layer or by decreasing sufficiently the rate of filtration, or by a combination of these two modifications, to obtain uniformly an effluent of satisfactory character and appearance from the local river water after plain subsidence for three days. But the cost of such procedures would clearly make them prohibitive.

To make use successfully at all times of English (slow sand) filters it would be necessary at times of freshets to give the Ohio River at Cincinnati further preparatory treatment than is afforded by three days of plain subsidence.

With respect to the modified slow sand filtration system

The evidence shows that the modified English (slow sand) system of purification is applicable to the Ohio River water at Cincinnati, based on the satisfactory clarification and purification of the water. It would, however, be very much more difficult to operate, and somewhat more expensive, than is understood to be the case with those purification works of the English (slow sand) method now in use at various cities.

With respect to the rapid sand filtration system

The evidence obtained during these investigations shows that it is practicable to clarify and purifiy the Ohio River water in a satisfactory manner by either the modified English (slow sand) system or by the American (rapid sand) system. Of these two systems, the experience and data indicate clearly that the American (rapid sand) system would be the less difficult to operate; would be somewhat cheaper; would give substantially the same satisfactory quality of filtered water; and could be much more readily and cheaply enlarged for future requirement. It is therefore considered that the American (rapid sand) system of clarification and purification would be the more advantageous to adopt for the local water supply.

The raw Ohio River water is first allowed to settle for some three days in a large reservoir, coagulant being then added and a period of from two to three hours allowed for coagulation and supplementary sedimentation to take place. The water is then applied to the rapid sand filters, of which there are twenty-eight 4,000,000 gallon units. The filter tanks are rectangular in plan and built of concrete. The filters and all appurtenances are contained within a brick building with a concrete roof. The filtered water basin is located outside the filter building, and has a capacity equal to about two hours supply when the plant is working under full load.

Results of operation of the Cincinnati rapid sand filtration plant, for the year 1910

Average gallons filtered per day		48,500,000
Grains per gallon	Lime	0.84
	Iron	1.79
Per cent wash water used		3.5
Turbidity parts per million—Average for Year	River	190
	Plain settled	80
	Applied	21
	Filtered water	0
Bacteria per cubic centimeter—Average for year	River	8900
	Plain settled	3200
	Applied to filters	750
	Filtered water	75

The figures given in the last table show that the Cincinnati rapid sand filter plant furnishes a filtered water free from turbidity, and containing less than one per cent of the bacteria originally present in the untreated Ohio River water.

As to the reduction in typhoid fever, the experience in Cincinnati has been very gratifying. The purification works went into service in 1908, and for eight years prior to that time the average death rate from the disease averaged 55 per 100,000 population. During the succeeding five years these rates fell to 19, 13, 6, 11 and 6 respectively per 100,000 an average of 11 for the period, or a reduction of 82 per cent.

Louisville, Kentucky. This rapid sand filtration plant, having a daily filtering capacity of 36,000,000 gallons, was placed in operation late in 1909. The raw Ohio River water is subjected to plain sedimentation in the old Crescent Hill reservoir, after which coagulant is added, a period of coagulation and supplementary sedimentation allowed, and the partially clarified water then applied to rapid sand filters.

As early as 1884 the filtration question was investigated at Louisville, but those earlier studies were confined to slow sand filtration. On account of the frequently muddy character of the Ohio River water at Louisville, these investigations showed that slow sand filtration could not efficiently and economically purify it.

In 1895 an exhaustive series of investigations into the merits of the rapid sand filtration process was begun. Numerous proprietary systems were studied, and it was largely the result of this work that placed the rapid sand filtration process intelligently before the world, and was in no small measure responsible for the rapid growth of the process from the year 1900 on.

The Louisville investigations were continued practically without interruption for two years, during which the conclusion was reached that it was entirely feasible to thoroughly clarify and otherwise purify the Ohio River water by plain sedimentation, coagulation and filtration through rapid sand filters.

The rapid sand filter plant which was later built has now been in successful operation for some five years. The year 1911 was a representative one, and the results of operation of the filtration works for that year are given in the following table:

Average results of operation of the Louisville rapid sand filtration plant for the year 1911

Daily volume of water filtered (gallons)		24,000,000
Sulphate of alumina used (grains per gallon)		1.73
Per cent wash water used		2.37
Turbidity (parts per million)	River water	225
	Filtered water	0
Bacteria (per cubic centimeter)	River water	10,300
	Filtered water	135

From the foregoing results it is seen that the filters produce from the muddy Ohio River water an effluent free from turbidity and containing but 1.3 per cent of the bacteria originally present in the untreated water. The volume of wash water used in cleaning the filters averaged 2.37 per cent of the total volume of water filtered.

As to the reduction of typhoid fever in Louisville the results are gratifying, showing a steady annual decrease since the filter plant went into service. For the 10 years ending 1909, and prior to the filtration of the water, the average death rate from typhoid fever in Louisville was 56; and during the three succeeding years it was 31, 25 and 19, respectively, an average of 25, or a reduction of 55 per cent.

Columbus, Ohio. This purification plant, put into operation in 1908, is designed to soften the very hard Scioto River water as well as to clarify and otherwise purify it. The works have a capacity of 30,000,000 gallons, the tanks and basins are built of reinforced concrete, and the buildings are of brick with tile roofs.

The plant comprises main reaction chambers, holding about one hour's flow as a minimum and wherein the bulk of the softening action takes place, coagulating basins, 12 in number, and allowing a period of about ten hours for coagulation and sedimentation, and 10 rapid sand filter units, each having a daily filtering capacity of 3,000,000 gallons. The filtered water basin, also built of concrete, is located underneath the filters, and has a capacity of 10,000,000 gallons.

The water which this plant is called upon to purify is not only frequently muddy, but is one of the hardest waters in the country. As delivered from the purification plant it is relatively soft and free from bacterial life, clear and palatable. The results of operation of this plant during a representative year are given in the following table:

Results of operation of the Columbus rapid sand filtration and softening plant for the year 1911

1911			HIGHEST DAY	AVERAGE FOR YEAR
Volume of water filtered daily. (Gallons)			19,700,000	14,900,000
Per cent of wash water used			....	1.3
Coagulating and softening chemicals used (grains per gallon)		Lime	....	7.5
		Soda ash	....	4.3
		Sulphate of alumina	....	1.57
Parts per million	Color	River water	75	28
		Filtered water	17	7
	Turbidity	River water	733	68
		Filtered water	0	0
	Total Hardness	River water	321	245
		Filtered water	110	84
	Alkalinity	River water	203	150
		Filtered water	73	45
	Incrustants	River water	131	45
		Filtered water	60	38
Bacteria per cubic centimeter		River water	220,000	11,470
		Filtered water	2,800*	55

*Abnormal. Caused by growths of harmless bacteria.

From the above results it is seen that the total hardness of the Scioto River was reduced on the average to less than 100 parts per million, a reduction of over 66 per cent., and the incrusting constituents to 38 parts, a reduction of 60 per cent. The bacteria in the raw water were reduced by 99.5 per cent on an average.

The reduction of typhoid fever in Columbus since the filtration works were put into operation in 1908 has been most gratifying. For the nine years prior to filtration of the water supply the average death rate from typhoid fever was 62; and for the four years following 1908 it was 17, 17, 14 and 19, respectively, averaging 17, and equivalent to a reduction of 73 per cent.

REASONS FOR WATER COAGULATION AND EFFECT THEREOF ON THE CHARACTER OF FILTER EFFLUENTS

One of the earliest objections of the rapid sand filtration process of water purification was the fact that the water was treated with a chemical in the preparation thereof for filtration. The layman, and indeed some sanitarians and many physicians, viewed with appre-

hension the use of alum and iron salts in connection with the purification of water, believing that some of the chemical passed through into the final effluent to the detriment of the person drinking it. Indeed, some hold this view today, even in the face of the fact that the claim was scientifically and practically exploded many years ago. It has also been claimed that the use of certain chemicals made the filtered water less desirable for steaming purposes, as, for example see the conclusions of the Pittsburgh Filtration Commission on page 40 of this paper.

Of late years there has been considerable discussion of "red water" troubles, that is, water to which a reddish brown color is imparted by suspended particles of iron oxide. It has been claimed by some that the bulk of complaints from red water troubles come from cities where the rapid sand filter process is used. It may be well, therefore, to dwell at some length upon the reasons why coagulation is an important adjunct to water filtration, and the actual effect which the addition of coagulating chemicals has upon the physical quality of filtered water.

DEFINITION OF COAGULATION

By coagulation is meant the use of certain harmless chemicals which, upon being added in minute quantities to water, produce a gelatinous precipitate that envelopes the mud, clay, organic matter and bacteria, and causes them to form into aggregates of such size that they can be much more easily removed, either by sedimentation or by filtration, than is the case with uncoagulated water. This treatment makes possible the adequate preparation of muddy water for final filtration, without the construction of large sedimentation reservoirs, wherein the removal of the mud in the water takes place very slowly and more or less incompletely.

COAGULATING CHEMICALS

The chemicals most commonly used for the coagulation of water are compounds of aluminum and iron, and of these potash alum, sulphate of alumina, and sulphate of iron are the most extensively employed.

The manufacture of alum is of great antiquity, and for many centuries this chemical has been used for coagulating water, as an aid to speedy clarification. The manufacture of alumina sulphate from

bauxite and limeclay is of more recent origin. The sulphate of iron used in water coagulation is, for the most part, a byproduct of iron and steel industries.

The choice between the different coagulating chemicals is partly based upon their efficiency as coagulants, and this refers directly to the percentage of available alumina or iron which they contain. In a general way it may be said that potash alum, and sulphate of alumina cost about 1 cent a pound, while sulphate of iron costs about ½ cent a pound. In this country sulphates of alumina and iron are the most widely employed in water purification.

In composition these chemicals show considerable variation, but they may be bought on a basis of a guaranteed percentage of available alumina or iron. The essential feature is that the chemical shall be basic, namely, that it shall contain more available alumina or iron than is required to combine with the dissolved sulphuric acid, and that it shall contain no free sulphuric acid. The approximate composition of these chemicals is as follows:

Approximate percentage composition of coagulating chemicals

CONSTITUENT	PURE POTASH ALUM	SULPHATE OF ALUMINA	SULPHATE OF IRON
Matter insoluble in water	....	0.30	0.50
Alumina (Al_2O_3)	10.77	17.00	....
Iron (Fe_2O_3 and FeO)	....	0.25	57.50
Potash (K_2O)	9.93	....	....
Sulphur trioxide (SO_3)	33.76	38.70	28.80
Water (H_2O)	45.54	43.75	13.20

ACTION WHICH TAKES PLACE UPON THE ADDITION OF COAGULATING CHEMICALS TO WATER

When potash alum or sulphate of alumina is applied to water, the chemical is rapidly and completely decomposed by the alkaline compounds naturally present in the water. Ordinarily this alkalinity is due to carbonates and bicarbonates of lime and magnesia. The sulphuric acid portion of the coagulating chemical displaces the weak carbonic acid of the alkaline compounds above mentioned. As a result soluble sulphates of lime and magnesia are formed and equivalent amounts of carbonic acid and alumina are liberated. The latter unites with the water and forms the white, insoluble and gelat-

inous precipitate, known as aluminum hydrate, and which has the property of massing together various impurities as mentioned above.

The amount of coagulating chemical that it is necessary to use depends upon the character of the water to be treated, especially the turbidity or color of such water. Very turbid or very highly colored waters frequently require several grains of coagulating chemical per gallon of water. At most plants, however, the annual average is not greatly in excess of 1 grain per gallon. This quantity is equivalent to about 17 parts per million by weight, or 143 pounds per million gallons of water treated.

One grain per gallon of sulphate of alumina requires for its decomposition about 7 parts per million of alkalinity, depending upon the precise strength of the chemical used. This means, as explained above, that 7 parts per million of the carbonates and bicarbonates of lime and magnesia naturally present in the untreated water are converted into the sulphates of lime and magnesia.

The total hardness of the water is unaffected by the application of coagulating chemicals, such as sulphate of alumina, when decomposed by the natural alkaline compounds of the water to be treated.

The amount of carbonic acid which is liberated for each grain of applied sulphate of alumina is equal to about 3.5 parts per million, roughly one-fifth of a grain per gallon.

Under some circumstances the liberation of carbonic acid seems to increase somewhat the rate at which clear filtered and oxygenated water corrodes certain forms of uncoated (unprotected) metal. It is not a factor to be regarded with apprehension because the conditions are no more conducive to corrosion than are found in some of the best ground water supplies of the country. If thought advisable, this carbonic acid may be removed by the addition of lime.

The average consumer cannot ordinarily detect any effect due to the addition of coagulating chemicals as they are bound to be decomposed in order to become effective. Neither can the ordinary consumer detect any changes as regards hardness, because the total hardness of the water is unchanged.

Where water is boiled or is used for steam-raising purposes, a water treated with a coagulating chemical is a little less satisfactory, but the effect is merely nominal when consideration is given to the large diminution in the accumulations formed within the boiler due to the elimination of mud where treated water is used.

As a general proposition all surface waters naturally contain a

sufficient quantity of alkalinity to completely decompose all of the chemical which is applied for coagulating purposes. In some waters, however, the natural alkalinity is so low, particularly at times of floods, that it is necessary to make up the deficiency by applying soda ash or lime to the water.

Sulphate of iron, known commercially as copperas, is the ordinary commercial byproduct in iron and steel industries. A somewhat higher grade of sulphate of iron is manufactured by a vacuum crystalizing process.

The use of sulphate of iron in water purification ordinarily requires for the precipitation of the iron the addition of lime. When added to a natural water, copperas is decomposed in a manner somewhat similar to alum, except that the resulting bicarbonate of iron is partly soluble and more or less granular. By adding lime bicarbonate of iron is changed to the gelatinous ferrous hydrate, which in turn is oxidized into ferric hydrate. The latter is insoluble and gelatinous, serving well in the massing together of impurities. To obtain satisfactory results from the use of lime and iron as coagulants it is necessary to add sufficient lime to neutralize and precipitate the iron. This must be done carefully. The use of too little lime results in poor coagulation, caused by the incomplete precipitation of the iron, some of which is usually left in solution, appearing in the effluent of the coagulating basin. The use of too much lime results in the formation of lime incrustants, which are liable to cause trouble through deposition in the sand bed and in pipes and valves.

COAGULATION IN THE PREPARATORY TREATMENT OF WATER FOR FILTRATION

Where waters in their raw state are normally clear and colorless, as is true in some parts of northeastern United States, practically no preparatory treatment is required before filtration. It is in connection with such waters as these, which more nearly approach in character the waters of western Europe, that purification by slow sand filtration, whose birthplace was in England, may be successfully practiced.

Waters which are comparatively clear but highly stained by decaying vegetation and which require treatment for the removal of bacterial life, may be purified by slow sand filtration. Such treatment however, will remove only a relatively small part of the color

dissolved in the water, and if it is desired to remove all of this color a coagulating chemical must be used. To use coagulants effectively and economically in connection with sand filters the period of preliminary coagulation and sedimentation should be at least 18 hours, and preferably 24 hours.

Many waters in the South and Central West are almost always more or less muddy. The waters of the Missouri, Mississippi and lower Ohio Rivers are good examples of this class of water. The suspended matters which cause these waters to be muddy are largely mineral, but vary greatly in the size of the particles. Some are comparatively coarse and settle out readily when the water is allowed to stand. Others are of exceeding fineness, many of them less than $\frac{1}{100,000}$ of an inch in average diameter, which is smaller than the ordinary bacterium. Turbid waters such as these, applied to filters without preliminary treatment, cannot be satisfactorily purified to the degree now demanded in this country.

It is in the purification of these muddy waters that some of the most difficult problems are found. The turbidity of many river waters shows abrupt changes from that of comparative clearness following long periods of drought, when the amount of suspended matter it contains may be less than 50 parts per million (430 pounds of dry mud per million gallons) to periods of great muddiness during freshets, when it may contain as much as 2000 or more parts per million (17,000 pounds or more per million gallons). At Pittsburgh the highest amount of suspended matter recorded in 1909 was 1300 parts per million, equal to 11,000 pounds of dry mud per million gallons. Changes from comparatively clear to very muddy water occur very suddenly at times, and the character of the suspended particles is subject to great variation.

To remove the great bulk of this suspended matter prior to filtration and to do it economically is not a simple problem. If it is done by plain sedimentation, then the basins in which subsidence takes place must be large enough to deal satisfactorily with the water when in its worst condition. If sedimentation is to be aided by preliminary coagulation, then the basins must be large enough to permit of adequate subsidence of the coagulated matters before the water reaches the filters. Otherwise the surface of the sand becomes clogged too quickly, requiring cleaning at prohibitively frequent intervals. Well baffled basins should have a capacity of eighteen to twenty-four hours' flow, and if the basins are not well baffled their

required capacity may be several days' flow in order to provide satisfactory results.

The practice of clarifying muddy water by coagulation with compounds of alumina followed by sedimentation probably originated in China thousands of years ago. It is certain that for many centuries it has been the practice in that country to treat tubs of turbid water with alum by inserting a crystal of the chemical in the split end of a stick and afterwards working the crystal up and down through the water until enough of the chemical has been dissolved to effect a satisfactory coagulation. It was used in Egypt for many centuries prior to its use at numerous plantations in the southern portions of the United States as an aid to the clarification of highly colored or very muddy waters. Coagulants have not had an extensive use in western Europe, owing to the comparative absence there of muddy or highly colored waters, but are now being used in quite a number of sand filtration plants in Belgium, Holland, and in Northern Germany. Among the larger cities may be mentioned Antwerp, Schiedam, Bremen and Hamburg.

The use of coagulants was not looked upon with great favor some ten or fifteen years ago either in this country or in Europe. Careful scientific investigation into the merits of their use at ten or a dozen places during the past fifteen years, particularly at Louisville, Pittsburgh, Cincinnati, Washington and New Orleans, and the complete absence of ill effects upon the health of communities using water regularly treated in this manner, have largely eliminated this feature from the public mind. Coagulating processes are now recognized as not only necessary for the treatment of certain classes of waters, but as permissible for use with perfect safety. The process has been carefully studied by the Royal Prussian Testing Station, and its merits now have an accredited standing in the majority of European countries.

At Cincinnati and New Orleans careful investigation with a view of ascertaining the feasibility of using coagulants in connection with the clarification of water passed through quite large settling basins before application to sand filters showed the process to be entirely feasible, although its expense was substantially greater than for mechanical filters. It was found necessary to have a settling capacity following the application of the coagulating chemical equal at least to an average flow of 18 hours and preferably 24 hours, otherwise some of the gelatinous precipitate would remain in the water as it

entered the sand filters and would clog the layer immediately at the surface so frequently as to make the cost of cleaning burdensome and abnormally expensive, as already stated.

The use of coagulants in connection with the preparatory treatment of water prior to its application to slow sand filters is quite successfully practiced in this country at Springfield, Massachusetts; Ferncliff and Poughkeepsie, New York; Indianapolis, Indiana; Washington District of Columbia and elsewhere.

Exclusive of filters of any kind and with sedimentation alone, coagulation is used for the clarification and purification of quite a number of water supplies of considerable size in the United States, among which may be mentioned Omaha, Nebraska; Leavenworth, Kansas; Kansas City, Missouri; and Nashville, Tennessee. In connection with rapid sand filter plants coagulants are always used, and at the present time there are some 450 such works in actual operation.

In the regular slow sand filtration processes, as practiced at Lawrence, Massachusetts, New Haven, Connecticut, and a few other smaller places, no coagulants are made use of, and there should not be caused by such filtration any change in the hardness of the water. In slow sand filtration as practiced at Washington, District of Columbia, Indianapolis, Indiana, and other places, where coagulants are used in the preparation of the water for slow sand filtration the effect of the added coagulant is, or should be, the same as that noted in rapid sand filtration processes. In any event the total hardness, and hence the soap consuming quality of the water, is neither increased or decreased, but the incrustants are slightly increased. Such increase in incrustants could hardly be detected by steam raisers, judged by incrustations in steam boilers. In fact it is decidedly probable that the elimination of the fine clay and silt obtained by coagulation would make the filtered water a more desirable boiler water than unclarified water.

The following results are given as illustrative of the actual changes in hardness which take place at some of the large filtration plants.

Hardness of river waters at various places before and after coagulation and filtration

CITY	AVERAGE FOR YEAR	KIND OF FILTERS	AMOUNT OF COAGULANT USED GRAINS PER GALLON	PARTS PER MILLION: Total Hardness, River	PARTS PER MILLION: Total Hardness, Filtered	PARTS PER MILLION: Incrustants, River	PARTS PER MILLION: Incrustants, Filtered	INCREASE OF INCRUSTANTS IN FILTRATED WATER DUE TO USE OF COAGULANTS
Springfield, Mass...	1912	Slow sand	(d) 0.24	11	11	2	4	2
Little Falls, N. J...	1903	Rapid sand	(d) 1.38	31	30	7	14	7
Louisville, Ky......	1912	Rapid sand	(d) 1.73	95	91	29	38	9
Cincinnati, Ohio....	1910	Rapid sand	(a) 0.84 (b) 1.79	76	89	32	41	9
New Orleans, La...	1912	Rapid sand	(a) 4.41 (b) 0.33	111	60	21	25	4
Columbus, Ohio....	1910	Rapid sand	(a) 7.5 (c) 4.3 (d) 1.57	270	85	111	35	Softened

(a) Lime; (b) Iron; (c) Soda Ash; (d) Sulphate of alumina.

The above results show practically all there is to the proposition that coagulation seriously affects the water for steam raising purposes. The data show positively that this cannot possibly be so. The only detrimental change which takes place is the formation in the water of some 6 or 8 parts per million of incrustants for every grain per gallon of coagulant used. Such small increase could not be measured detrimentally by the steam user, and the undesirable features surrounding their presence in the filtered water are more than offset by the advantages inherent in a boiler water which is free from silt and clay.

THE RED WATER QUESTION

Although the entire question of corrosion of metals by water has been given considerable attention by chemists and engineers ever since the general introduction of public water supplies in this country, of late years there has been considerable active agitation of this proposition and a tendency has been shown to attach a large measure of responsibility for the appearance of iron rust in water to alleged increases in the corrosive properties of water caused by the use of certain chemicals used in the course of its purification. Thus more or

less recently there has been a great deal of discussion of the so-called "red water plague."

It is a well established fact that pure iron is in some considerable measure soluble in pure water; also that the presence of oxygen enhances the corrosive action of water on iron. The oxygen of course oxidizes the iron dissolved in water and forms iron rust, and this imparts a reddish color to the water.

All surface waters, in the absence of gross pollution or complete stagnation, contain some dissolved oxygen, in amounts ranging up to 8 or 10 parts per million. In ground waters the amount of dissolved oxygen is generally less than in surface waters. Pure soft waters will corrode metal pipes, as will even pure rain water. Neutral salts in water will also cause corrosion, but are of considerable significance from the standpoint of the aid they offer in the formation of protective coatings in pipes.

Free carbonic acid increases the corrosive action of water on metals, and is usually present in all ground waters and in the majority of surface waters. The ground water supplies of Lowell, Framingham and Malden, Massachusetts, contain from 7 to 25 parts per million of carbonic acid; and the surface supplies of other cities in the same state contain as high as 15 parts at times. At Pittsburgh, in 1912, the free carbonic acid in the Allegheny River water was at times as high as 18 parts per million, and the average for the year was about 7 parts. At Springfield, Massachusetts, in 1912, at the West Parish filter plant, the river water contained from 2 to 3 parts. The Scioto River water at Columbus, Ohio, contains about the same amount. At Little Falls, New Jersey, the colored Passaic River water in 1912 contained on an average 8 parts per million of free carbonic acid. On some days it contained as much as 15 parts.

So far as filtration processes are concerned, where slow sand filters are used without the aid of a coagulant, and where the water contains substantial quantities of carbonaceous organic matter, the bacterial processes active in these filters cause an oxidation of such matter. An increase in the amount of carbonic acid in the water is the result. In the case of rapid sand filters, or slow sand filters, where sulphates of iron or alumina are used in the preparation of the water for filtration and where lime or soda are not also used, there is an increase in the amount of carbonic acid to the extent of some 3 to 4 parts per million for each grain of coagulant used per gallon of water treated. At Little Falls, New Jersey, in 1912, the river water contained on an

average 8 parts per million of free carbonic acid, and due to the use of 1.5 grains of sulphate of alumina per gallon of water the free carbonic acid in the filtered water as it left the plant averaged 15 parts for the year, an increase of something less than 5 parts per million for each grain of sulphate of alumina used per gallon of water treated.

Within the limits of ordinary practice in the use of coagulating chemicals in water purification in this country, the assumption that the increase in free carbonic acid caused by such chemical treatment is responsible for the more or less common run of red water troubles cannot be substantiated. Such troubles are encountered in cities having pure ground water supplies, as well as in cities using the old style slow sand filtration. The cause is not one common to all cases or localities, but is due as much, and in many instances more, to the natural character of the water supply itself, regardless of the manner in which it is purified.

RELATIVE COST OF SLOW SAND AND RAPID SAND FILTRATION

Construction. In discussing the cost of building water filtration works of the slow sand and rapid sand types, respectively, consideration will be given only to those items referring to the filter plant proper. Cost of land, pumping machinery, outside connecting piping, intakes etc., in fact everything outside the filtration plant proper, will not be considered.

For slow sand filter costs the items will include the necessary filter buildings and filters with all appurtenances, all inside piping, sand handling apparatus, preliminary sedimentation basins, preliminary filters and appurtenances and clear water reservoirs.

For rapid sand filter costs the items will include the filter buildings and filters with all appurtenances, all inside piping, filter washing apparatus, coagulating and clear water basins. Thus a fairly good idea may be had of the relative cost of building purification plants of the two types.

It is true that, on account of the much greater area required, the cost for land is far greater in the case of slow sand filtration systems than for rapid sand systems. Roughly, other things being equal, land will cost twenty times as much for a slow sand filter installation as for a rapid sand plant. Furthermore, in large projects, it is often difficult conveniently to locate a site for slow sand filters, while for a rapid sand filter plant it is a relatively easy matter as a rule. If

it is necessary to go a long distance in locating an extensive and suitable area of land for a slow sand filter site there is incurred a large expense for a conduit to bring the filtered water to the city. This is very rarely necessary in the case of rapid sand filter projects. So that, in studying the comparative figures which follow, it must distinctly be borne in mind that the costs given for slow sand filter installations are really low, since the important considerations just mentioned are not charged against them.

Cost of construction of slow sand and rapid sand water filtration plants

CITY	KIND OF FILTERS	PRESENT DAILY FILTERING CAPACITY	APPROXIMATE COST PER MILLION GALLONS DAILY CAPACITY
Albany, N. Y.	Slow sand	20,000,000	$20,000 (a)
Pittsburgh, Pa.	Slow sand	200,000,000	26,000 (a)
Philadelphia, Pa.:			
Torresdale	Slow sand	250,000,000	37,700 (a)
Upper Roxborough	Slow sand	28,000,000	29,800
Lower Roxborough	Slow sand	17,000,000	26,300 (a)
Belmont	Slow sand	60,000,000	45,200 (a)
Washington, D. C.	Slow sand	100,000,000	30,000 (b)
Cincinnati, Ohio	Rapid sand	112,000,000	11,400 (c)
Columbus, Ohio	Rapid sand	30,000,000	13,000 (d)
Dallas, Texas	Rapid sand	15,000,000	13,000
Harrisburg, Pa.	Rapid sand	16,000,000	10,300
Little Falls, N. J.	Rapid sand	32,000,000	15,000
Lorain, Ohio	Rapid sand	6,000,000	14,000
New Milford, N. J.	Rapid sand	24,000,000	11,000
Watertown, N. Y.	Rapid sand	8,000,000	11,250
Weighted averages	Slow sand	...	$32,600
	Rapid sand	...	12,100

(a) Cost of preliminary filters included.

(b) Cost of Dalecarlia Reservoir not included. Cost of McMillan Park Reservoir included, and also cost of remodeling Georgetown Reservoir, as well as cost of coagulating basin.

(c) Cost of large plain sedimentation basin not included.

(d) Cost of softening works not included.

The above figures show that the approximate relative cost of building the slow sand and rapid sand filter plants mentioned was $32,600 and $12,100, respectively, per million gallons daily capacity. At 5 per cent the fixed charges on these sums would amount to $4.47 and $1.66, respectively, per million gallons of water filtered.

OPERATION AND MAINTENANCE

The cost of operation and maintenance of filtration plants in a large measure, varies, of course, with the quality of the raw water. In a general way the following examples will serve to show the charges ordinarily made against the operation and maintenance of representative water filter plants in this country.

Cost of operation and maintenance of slow sand and rapid sand filtration plants

YEAR	CITY	KIND OF FILTERS	AVERAGE VOLUME OF WATER FILTERED DAILY	COST OF OPERATION AND MAINTENANCE PER MILLION GALLONS OF WATER FILTERED
			gallons	
1911	Albany, N. Y.	Slow sand	20,000,000	$2.50
1912	Pittsburgh, Pa.	Slow sand	100,000,000	3.41
1911	Philadelphia, Pa.	Slow sand (a)	9,000,000	5.62
1911	Philadelphia, Pa.	Slow sand (b)	13,000,000	3.59
1911	Philadelphia, Pa.	Slow sand (c)	38,000,000	3.88
1911	Philadelphia, Pa.	Slow sand (d)	202,000,000	1.91
1912	Washington, D. C.	Slow sand	62,000,000	4.01
1912	Cincinnati, Ohio	Rapid sand	50,000,000	4.12
1911	Harrisburg, Pa.	Rapid sand	9,000,000	3.93
1912	Little Falls, N. J.	Rapid sand	30,000,000	3.20
1912	Louisville, Ky.	Rapid sand	25,000,000	3.48
1912	New Orleans, La.	Rapid sand	16,000,000	6.32
Weighted Average		Slow sand	....	$2.86
		Rapid sand	....	4.04

(a) Lower Roxborough; (b) Upper Roxborough; (c) Belmont; (d) Torresdale.

To summarize, the average cost of building seven of the largest and most modern slow sand filter plants was $32,600 per million gallons daily capacity; and, likewise, the average cost of building six of the largest, and two medium size, rapid sand filtration plants was $12,100 per million gallons daily capacity. The average cost of operation and maintenance varied widely, of course, but averaged $2.86 and $4.04 per million gallons of water filtered by the slow sand and rapid

sand systems, respectively. Adding these last figures to the fixed charge on the first cost of construction makes up the following totals:

Slow sand filtration	$7.33 per million gallons
Rapid sand filtration	5.70 per million gallons

RELATIVE HYGIENIC EFFICIENCY OF SLOW SAND AND RAPID SAND FILTERS

In former years the slow sand process of water purification was favored by the majority of sanitarians and engineers because it was considered that, as compared with the rapid sand process, the former process was more nearly a "natural" one and hence less liable to failure. The actual results obtained from both systems have long since shown this assumption to be unfounded. Both processes require careful and intelligent management, but there is no room for doubt that if there is any choice between the two as regards hygienic efficiency it belongs to the rapid sand process. Well designed and built plants of this type not only can purify water of any character, turbid, colored or clear, so that the filtered product will always be clear and colorless, but are less liable to show sharp diminution in bacterial (hygienic) efficiency in cold winter months, or when the character of the raw water is seriously contaminated with certain industrial wastes. Chemical treatment is an integral part of all rapid sand filter processes, but is a makeshift when used in conjunction with slow sand filter processes; and the more complicated the chemical treatment prior to filtration the more likely are the final slow sand filters to fail.

In brief, wherever, chemicals are or should be used in the preparation of water for filtration, it is proof that the slow sand filter is out of its element and in a field which, on grounds of economy at least, belongs exclusively to the rapid sand system.

In support of the assertion that rapid sand systems are at least the equal of slow sand systems with respect to hygienic efficiency, the following results are presented showing the typhoid fever death rate in certain American cities using slow sand or rapid sand filters. Here it is seen that the residual typhoid in those cities having rapid sand filters is 27 percent less than in those having slow sand filters. This is the best evidence available of the hygienic superiority of rapid sand filtration.

Typhoid fever death rates before and after purification of water supply by slow sand or rapid sand filters

CITY	KIND OF FILTRATION	NUMBER OF YEARS AVERAGED		TYPHOID FEVER DEATH RATE PER 100,000 POPULATION	
		Before Filtration	After Filtration	Before Filtration	After Filtration
Lawrence, Mass.	Slow sand	20	20	109	23
Albany, N. Y.	Slow sand	10	13	90	21
Washington, D. C.	Slow sand	6	6	57	31
Philadelphia, Pa.	Slow sand	8	5	54	22
Pittsburg, Pa.	Slow sand	9	4	125	10
New Haven, Conn.	Slow sand	7	6	46	25
Indianapolis, Ind.	Slow sand	7	6	85	25
Paterson, N. J.	Rapid sand	5	10	32	9
New Orleans, La.	Rapid sand	10	3	38	25
Cincinnati, O.	Rapid sand	8	5	55	11
Louisville, Ky.	Rapid sand	10	3	56	25
Columbus, O.	Rapid sand	9	4	62	17
Scranton, Pa.	Rapid sand	12	2	20	9
Average	Slow sand	9	9	81	22
	Rapid sand	9	5	44	16

COMPARATIVE GROWTH OF RAPID AND SLOW SAND FILTRATION IN THE UNITED STATES

The growth of water filtration in the United States, particularly during the last dozen years or so, has been remarkable. In 1900 but 1,860,000 people were being supplied with filtered water, and in 1905 this country was inferior to Japan in this regard. Since 1900 the population so supplied has increased by 830 per cent.

In the decade 1900–1910 slow sand filtration showed a remarkable increase with respect to the population supplied from such plants. This was largely due to the construction of the plants in Philadelphia, Pittsburgh and Washington, these three cities contributing over 2,000,000 of the increased population served by that system of filtration noted in the decade 1900–1910, namely 3,523,000. The increase during the same period in the number of people supplied with water from rapid sand filter plants was even more remarkable, totaling 5,422,000, or 54 per cent greater than in the case of the slow sand filter systems.

Since 1910 the slow sand filter has failed to maintain the rate of increase noted during the previous decade, the additional population served at this date, as compared with 1910, being 1,515,000. During the same period the additional population served by rapid sand filters was 4,971,000. The proof is plain, therefore, that the slow sand filter has about reached its limit, while the rapid sand filter is growing faster each succeeding year.

The following tables and diagrams will serve to show how the practice of water filtration has grown in this country, and the respective parts which slow sand and rapid sand filter processes have played in the development of this important branch of municipal sanitation.

Population of the United States supplied with filtered water at different dates

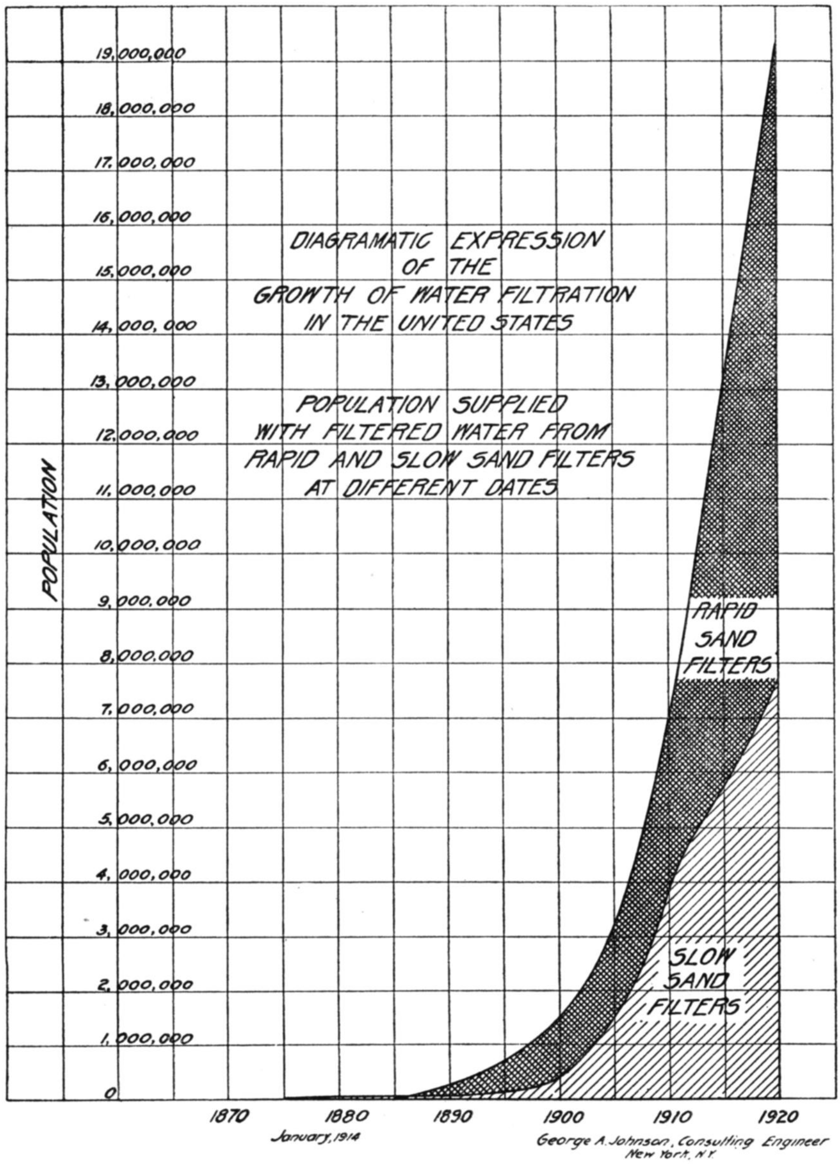
YEAR	TOTAL URBAN POPULATION IN PLACES OF MORE THAN 2,500 INHABITANTS	POPULATION SUPPLIED WITH FILTERED WATER			PER CENT OF URBAN POPULATION SUPPLIED FROM		
		From slow sand filters	From rapid sand filters	Total	Slow sand filters	Rapid sand filters	Total
1870	....	None	None	0	0.00	0.00	0.00
1880	13,300,000	30,000	None	30,000	0.23	0.00	0.23
1890	21,400,000	35,000	275,000	310,000	1.16	1.28	1.44
1900	29,500,000	360,000	1,500,000	1,860,000	1.22	5.09	6.31
1910	38,350,000	3,883,000	6,922,000	10,805,000	10.13	18.05	28.18
1914	42,500,000	5,398,000	11,893,000	17,291,000	12.70	27.98	40.68
*1920	48,200,000	7,670,000	19,350,000	27,020,000	15.91	40.15	56.06

* All figures on this line estimated, and based on the assumption that rates of increase during the entire period 1910–20 will be in proportion to those during the period 1910–14.

Population of the United States supplied with water purified by slow sand filters and rapid sand filters at different dates

POPULATION SUPPLIED WITH FILTERED WATER				INCREASE SINCE LAST DATE			
Year	From slow sand filters	From rapid sand filters	Total	Slow sand filters	Rapid sand filters	Total	Per cent which rapid sand filters increase was of the total increase
1880	30,000	0	30,000	....	....	....	....
1890	35,000	275,000	310,000	5,000	275,000	280,000	98.2
1900	360,000	1,500,000	1,860,000	325,000	1,225,000	1,550,000	79.0
1910	3,883,000	6,922,000	10,805,000	3,523,000	5,422,000	8,945,000	60.6
1914	5,398,000	11,893,000	17,291,000	1,515,000	4,971,000	6,486,000	76.6
*1920	7,670,000	19,350,000	27,020,000	2,272,000	7,457,000	9,729,000	76.6

*All figures on this line estimated, and based on the assumption that rates of increase during the entire period 1910–20 will be in proportion to those during the period 1910–14.


DIAGRAMATIC EXPRESSION
OF THE
GROWTH OF WATER FILTRATION
IN THE UNITED STATES
POPULATION SUPPLIED
WITH FILTERED WATER FROM
RAPID AND SLOW SAND FILTERS
AT DIFFERENT DATES
POPULATION
19,000,000
18,000,000
17,000,000
16,000,000
15,000,000
14,000,000
13,000,000
12,000,000
11,000,000
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
RAPID
SAND
FILTERS
SLOW
SAND
FILTERS
1870
1880
1890
1900
1910
1920
January, 1914
George A. Johnson, Consulting Engineer
New York, N.Y.

DISTRIBUTION OF POPULATION SUPPLIED WITH WATER PURIFIED BY RAPID AND SLOW SAND FILTERS, AND DISTRIBUTION OF PLANTS OF THESE TYPES

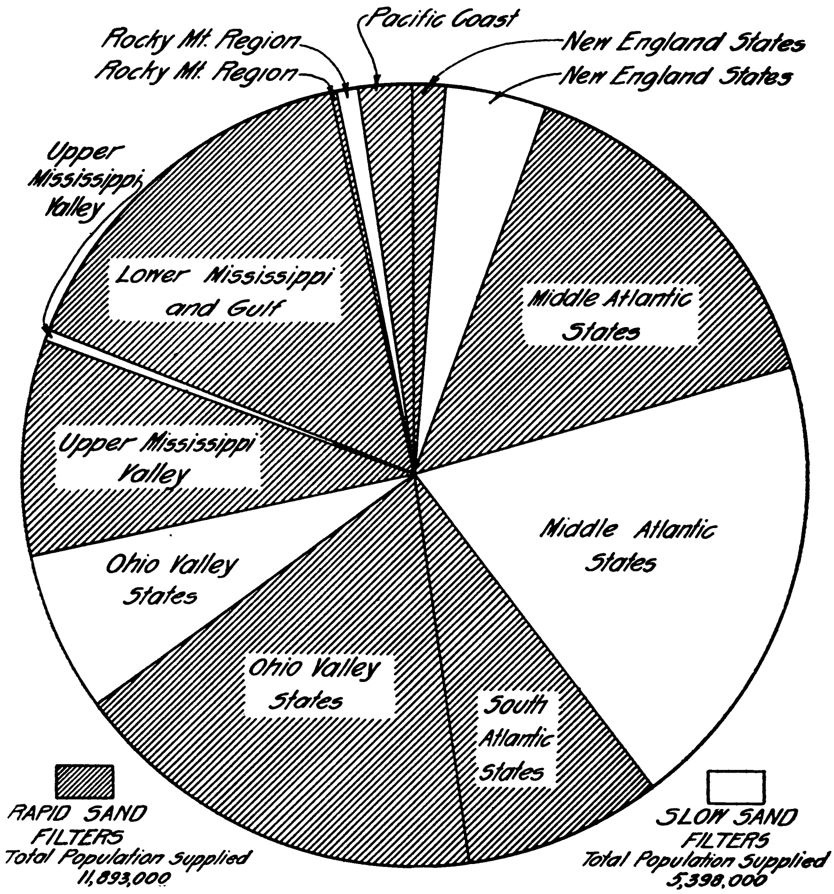
The next two diagrams will serve to show the manner in which the population supplied with filtered water is distributed. In New England, more nearly the rightful home of slow sand filtration than any other district in America, the population supplied by slow sand filters is greater than that supplied by rapid sand filters, while the total capacity of the latter plants is somewhat larger than that of the former. In the Middle Atlantic States the rapid sand filter is superior to the slow sand filter in point of population supplied and capacity of plants. In the South Atlantic States there are numerous rapid sand filter plants, but none of the slow sand type. In the Ohio Valley the rapid sand filter predominates, Pittsburgh being the largest representative of the slow sand process in that district. The upper Mississippi Valley is represented almost exclusively by rapid sand filters, and the Lower Mississippi and Gulf Region is entirely in the rapid sand filter class. In the Pacific Coast and Rocky Mountain Region the rapid sand filter predominates.

SUMMARY AND CONCLUSIONS

To the writer the data at hand furnish indubitable evidence of the obsolescence of slow sand filtration, and the steady rise of rapid sand filtration. When taking for comparison the relative growth of filtration in the United States by the two methods, it is clear that from the beginning the rapid sand method has predominated until, at the present day nearly 69 per cent of the total population of this country supplied with filtered water are served by rapid sand filters.

The first municipal slow sand filter in this country was built in 1875, and the first rapid sand filter in 1885, Since those dates the average annual number of people served by slow sand and rapid sand filter plants was 145,000 and 425,000, respectively, showing in this comparison the rapid sand filter practice to have been the superior of slow sand practice by some 200 per cent.

The decade 1900–1910 was a remarkable one in the line of water filtration development. Slow sand filters were built in many large cities, including Pittsburgh and Philadelphia, Pennsylvania, and Washington, District of Columbia; and rapid sand filter plants were placed in operation in such cities as Cincinnati, Columbus and



GEOGRAPHIC DISTRIBUTION
OF POPULATION SUPPLIED WITH WATER
PURIFIED BY
RAPID AND SLOW SAND FILTERS

RELATIVE POPULATION
SUPPLIED BY DISTRICTS

January, 1914

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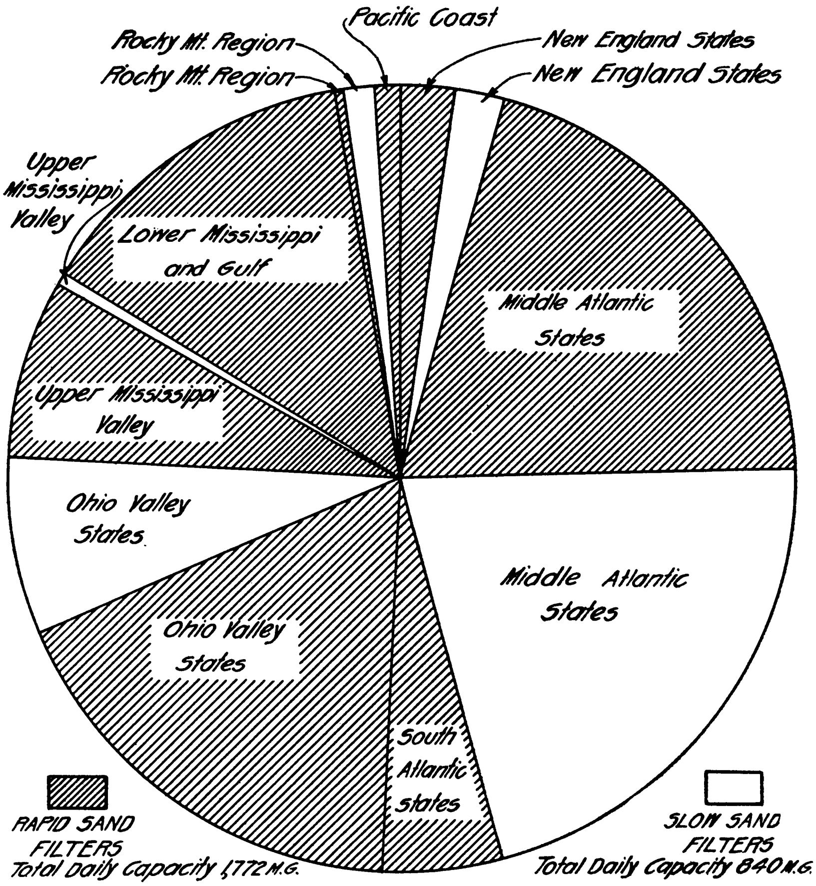

GEOGRAPHIC DISTRIBUTION OF FILTRATION PLANTS OF RAPID AND SLOW SAND FILTER TYPES

RELATIVE DAILY FILTERING CAPACITIES BY DISTRICTS

January, 1914

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Toledo, Ohio; Harrisburg, Pennsylvania; Louisville, Kentucky; New Orleans, Louisiana; and Paterson, New Jersey. All told, in that decade filter plants were built to serve a total of 8,945,000 people. When it is recalled that at the beginning of that decade only 1,860,000 people were supplied with filtered water, the contrast becomes particularly marked.

Since 1910 progress has continued. Filter plants have been built and placed in operation, or are now under construction in such cities as Baltimore, Maryland; Dallas, Texas; Evanston, Illinois; Grand Rapids, Michigan; Minneapolis, Minnesota; Portsmouth, Ohio; St. Louis, Missouri; Trenton New Jersey; and elsewhere. All of these plants are of the rapid sand type, and it is significant that no new slow sand filter plants of size have been built since 1910, the work on filter plants of this type having been for the most part restricted to alterations and improvements whereby the efficiency of existing plants would be improved through the addition of coagulating or other preparatory processes.

From these facts it is readily seen that the rapid sand filter process not only predominates at this date, but bids fair to supplant before long, in a number of instances, the existing slow sand filter plants.

It has been demonstrated by actual experience that slow sand filters without the aid of costly preparatory treatment, cannot efficiently purify such waters as those of the Hudson River at Albany, the Delaware at Philadelphia, the Potomac at Washington and the Allegheny at Pittsburgh. And even with preliminary filters there are cases where not only the appearance of the slow sand filtered water is at times unsatisfactory, but high bacterial efficiency at such times is obtained only with the aid of a supplementary sterilization process.

The hygienic efficiency of water filtration processes, measured by the reduction in typhoid fever, may be said to be about 70 per cent. There is little to choose between the average well built and operated slow sand and rapid sand filter, although such advantage as there is rests with the rapid sand filter process which *demands* expert supervision, as should all means operated to the end of saving human life. Slow sand filters, even the simplest kind, and particularly those modified after the fashion of Philadelphia, Albany, Washington and Pittsburgh, *also demand* expert supervision. It is folly to consider the matter in any other light.

Questions of cost alone should never govern the manner of dealing with problems affecting public health and comfort. It so happens,

however, that slow sand and rapid sand filtration cost about the same, with the advantage of lower cost usually in favor of the rapid sand process. A human life is customarily valued at $5,000, and a difference of even $15 per million gallons for water purification, one way or the other, amounts in a year's time to about the value of one human life.

Years of personal study, and reasonably thorough familiarity with the performances of both types of water filters in scores of cities, forces the writer to the conclusion that in the efficient and economical solution of the vast majority of water purification problems in the United States, the rapid sand filtration process is superior to the slow sand process. In view of the general trend during the past ten years or more toward the rapid sand process, and away from the slow sand process, it would seem that the writer is by no means alone in the conviction which he holds.

King James, it will be remembered, used to call for his old shoes, for they were easiest for his feet, and there are some who still prefer the old type filter for the reason that they believe it will run itself, and is therefore less of a constant bother; but in view of the experience of the last twelve or more years the writer prefers the newer process of water purification because there is *no question* about its requiring constant skilled attention; because it is sure in its action; because it insures a minimum typhoid fever death rate coincidentally with the production of a clear, colorless and palatable water; and because it is no more costly than the older type of filtration process.

When one buys an expensive piece of machinery he doesn't turn it over to the questionable mercies of an unskilled mechanic. It is the same with a filter plant which costs far more money. The argument favoring the slow sand filter because it *cannot* go wrong is fallaceous and nonsensical. If properly operated it also requires skilled supervision; and most of the so-called slow sand filter plants of today require a good deal of that.